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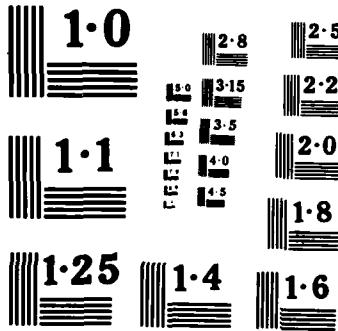
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AND THE DRIVER

Kenneth A. Solomon

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May 1985

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## ABSTRACT

This paper identifies three groups that can improve automotive safety. The three groups are the automotive industry by designing into cars such safety devices as seat belts, roll bars, or air bags; the government by taking such measures as improving road conditions, enforcing seat belt usage laws, or enforcing stricter anti-drunk-driving laws; and finally, the driver by modifying driving habits such as wearing seat belts and not driving while intoxicated.

Of the seven strategies we define for improving automotive safety, this paper argues that "as low as reasonably achievable" (ALARA) is the most applicable risk reduction strategy within the context of improving automotive safety. By applying the ALARA principle to past and proposed safety improvements, we demonstrate that the most lives saved per dollar spent would occur if drivers modified their driving habits.

## PREFACE

This paper is written in briefing format and is intended to serve two purposes. First, it will be presented at The International Society of Risk Analysis meeting (October 1985, Washington, D.C.), and second, it will support a Rand Graduate Institute course and a University of California at Los Angeles tutorial entitled *Risk and Uncertainty in Public Policy Decisions*.

The paper examines alternative means of improving automotive safety.

## CONTENTS

<b>ABSTRACT</b> .....	<b>iii</b>
<b>PREFACE</b> .....	<b>v</b>
<b>FIGURES</b> .....	<b>ix</b>
<b>TABLES</b> .....	<b>xi</b>
Section	
<b>I. OBJECTIVES</b> .....	<b>1</b>
<b>II. DEFINITIONS</b> .....	<b>2</b>
Identifying Alternative Risk Reduction Goals .....	2
Why ALARA? .....	6
Defining Roles in Improving Safety .....	7
<b>III. ANALYSIS</b> .....	<b>10</b>
Costs of Risk Reduction .....	10
Approximate Dollars Spent per Averted Fatality .....	11
What the Automobile Industry Has Done To Improve Safety ...	20
<b>IV. IMPLICATIONS</b> .....	<b>23</b>
The \$10,000,000 Menu .....	23
The Bottom Line .....	25
<b>REFERENCES</b> .....	<b>27</b>

## FIGURES

1.	Defining Industry/Law Enforcement/Driver Role in Improving Safety: A Typical Issue .....	9
2.	Fatalities and Use of Seat Belts .....	16
3.	Measures Implemented by the Automotive Industry To Improve Safety .....	21
4.	The \$10,000,000 Menu: Save As Many Lives As You Can .....	24

**TABLES**

1.	Alternative Risk Reduction Goals .....	5
2A.	Approximate Dollars per Averted Fatality .....	12
2B.	Approximate Dollars per Averted Fatality (Continued) .....	12
2C.	Approximate Dollars per Averted Fatality (Continued) .....	13
2D.	Approximate Dollars per Averted Fatality (Continued) .....	13
2E.	Approximate Dollars per Averted Fatality (Continued) .....	14
3.	Repair Cost Savings from 1973 Improved Bumper Design .....	18

## I. OBJECTIVES

The purpose of this paper is to attain the following four objectives:

- Review generic risk reduction, or safety improvement, goals;
- Select one particular goal to examine in detail;
- Apply this goal to improving automotive safety; and
- Discuss how three distinct groups can implement this goal.

The goals will be discussed later. With regard to our fourth objective, the three groups that can implement our selected goal are industry, the government, and drivers themselves. Industry can improve safety by adding protective devices such as seat belts and air bags to automobiles [1-8]. Government can improve safety at each of three levels: federal, state, and local administrations [2, 3, 6-12, 13].

Each level of government must play its respective role to the fullest to attain the highest possible automotive safety standards. For example, the state must maintain highways and roads sufficiently. State and local law enforcement agencies must strictly enforce laws against speeding, moving violations, and drunk driving. Judicial systems must strictly punish lawbreakers to prevent recurrent offenses as well as to deter prospective offenders. Last, each driver can influence safety through good driving habits. Buckling seat belts, obeying speed limits, and not driving while intoxicated are several positive habits that will improve automotive safety [2, 3, 6-8, 14-17].

## II. DEFINITIONS

### IDENTIFYING ALTERNATIVE RISK REDUCTION GOALS

Although the safety level of any technology can always be improved, there is no unique approach or philosophy for making such improvements [18-20]. Several prior studies have identified a number of distinct philosophies for reducing risk associated with various technologies. Seven measures to reduce risk and achieve specific safety levels are discussed below [18]. Imbedded within this discussion are examples specific to automotive safety.

#### **What Are Some Alternative Risk Reduction Goals?**

**Minimizing maximum accident consequence** is one method to reduce the risk associated with automobile operation. For example, we can eliminate all accidents involving a large number of fatalities in a single transportation event. This could be achieved, for example, by preventing all fully occupied buses from driving on any highway or road. Because the maximum number of passengers on board a bus could be 50 or 60, the worst possible accident would cause the death of 50 to 60 people. This particular philosophy seeks to reduce total risk by minimizing the maximum number of people that could be killed in any single accident. Another application of this philosophy is to require that not more than two people occupy any one car at a time, and that cars be positioned far enough apart to eliminate the possibility that two cars could ever be involved in an accident. We would minimize the maximum number of fatalities per accident to four in this case. Of course, this is neither a realistic nor a feasible risk reduction goal when applied to automotive safety. The impracticality of trying to reduce the number of people riding in any one vehicle at a given time outweighs any benefits gained.

**Minimizing the probability of occurrence for the most probable types of accidents** is a second method of improving safety which thereby reduces risk. Because rear-end collisions are a common type of accident, an extreme application of this approach would seek to

eliminate all rear-end collisions [2, 3, 9-13]. To fully ensure that all rear-end accidents are eliminated we would have to permit only one car on the road at a time, an obviously impracticable solution. A more practicable one requires the use of center-mounted, high positioned brake lighting. Use of such a light would reduce rear-end collisions by more than half [2, 3, 10-12]. We would also try to identify other types of common accidents to reduce their probability as well.

**Minimizing the total accident risk** is a third risk reduction goal. Risk is defined as the probability of an event times the consequence (or outcome) of that event integrated over all negative events. Therefore, as we apply this goal to automotive safety we find that we need to reduce both the total *number* and the *intensity* of accidents (i.e., limit both the total number of buses on the road and the number of passengers per bus).

**Eliminating all accidents** is a fourth risk reduction goal that appears to be unattainable in any context, however it is applied. Enforcement of the Food and Drug Act's Delaney Clause has prevented the use of any carcinogenic food additive [18]. Presumably this would eliminate the incremental cancer risk that we derive from using food additives. However, within the context of automotive safety, the only way to eliminate all occurrences of property damage, injuries, and fatalities would require that no automobile is ever permitted to operate.

**Requiring those who partake in the benefits to take a proportional share of the risk** is a fifth risk reduction goal. Applying this broad goal to automotive safety, we find this is exactly what happens. For example, the more miles one drives per year, either as a driver or passenger, the greater one's probability of being involved in an accident [2, 3]. When this goal is applied to other aspects of automotive safety it becomes complicated. Risks and benefits are not always comparable. The risk of injury to passengers of small cars is greater than the risk to those in large cars. However, the benefits of smaller cars are different. Smaller cars offer better fuel economy-- a benefit that may compensate for the higher risk of injury.<sup>1</sup>

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<sup>1</sup> It is interesting to note that passengers of sports cars have a more severe injury and fatality rate than their counterparts in larger cars [14]. Yet, sports cars are far less likely to cause an accident [18].

**Minimizing the socially perceived risks** is risk reduction goal number six. These are risks *perceived* to be large, but are not technically or quantitatively large [18-20]. For instance, suppose a passenger bus with 40 occupants falls off a 100-foot cliff, and there are no survivors. This is socially perceived as far worse than 40 individual, fatal accidents. By eliminating all spectacular or well-publicized events we minimize the socially perceived risk. Another example of minimizing this risk is to eradicate all fire-related automobile accidents, regardless of whether or not the fire caused the fatality. While we may perceive this risk reduction measure as socially desirable, it may in fact be costly to implement, and may not reduce the annual number of fatalities.

**Reducing risk to as low as reasonably achievable** (referred to here as ALARA) is our seventh risk reduction goal. Application of the ALARA goal to industry, government, or individual drivers requires a fixed budget to reduce the total accident risk to *as low as reasonably achievable*.

Table 1 summarizes these seven risk reduction goals.

#### **Which Goal Makes the Most Sense?**

We will deduce which one of the seven goals makes the most sense when applied both to general situations and to the specific issue of automotive safety. First, Goal 1 (minimize the probability) and Goal 2 (minimize the consequence) are contained in Goal 7, the ALARA Goal. Therefore, we will not lose anything by eliminating Goal 1 or Goal 2 as long as we still consider the ALARA Goal.

Minimizing total risk, Goal 3, is really a special case of the ALARA Goal. In this special case, there are no budgetary constraints. We minimize total risk without considering how much it costs to minimize such risks and there is no risk/cost tradeoff.

Goal 4 seeks zero total accident risk. The only way to completely avoid all automobile accidents is to eliminate all vehicles from the road. Obviously, this solution is not practicable when applied to

Table 1  
ALTERNATIVE RISK REDUCTION GOALS

---

- (1) Minimize the maximum accident consequence (e.g., eliminate accidents involving large number of mortalities in a single event).
- (2) Minimize the probability of the more probable accident types (e.g., determine that rear-end collisions are a probable type of accident and reduce their frequency).
- (3) Minimize total accident risk (e.g., for all types of automotive accidents, reduce the product of their frequency and outcome).
- (4) Reduce total accident risk to zero (e.g., zero fatalities per year and zero injuries per year (i.e., eliminate the automobile)).
- (5) Share risks and benefits equitably (e.g., the more miles you drive per year, the higher the risk you take).
- (6) Minimize socially perceived risks (e.g., eliminate spectacular accidents such as a bus falling off a 100-foot cliff)
- (7) Reduce risk to ALARA (e.g., for a fixed budget, reduce total accident risk to as low as possible).

---

automotive safety, even though it may have been for carcinogenic food additives (Delaney Clause).

Minimizing socially perceived risks is also difficult to attain (Goal 5 includes removing large-scale or spectacular accidents). In addition to being difficult to attain, this philosophy does not have a predictable payoff. We have illustrated that total risk may remain unchanged (recall the 40 passenger bus accident versus the 40 individual accidents). In fact, Goal 5's application could result in a substantial increase of total risk if different types of accidents are traded off against one another [18-20].

As we have discussed, Goal 4 (sharing risk proportionately with benefit) is implicit in any automotive design issue.

Finally, we feel the ALARA Goal makes the most sense. By definition it is intended to provide the most safety at the smallest dollar cost.

percent of the total number of cars on the road, then perhaps 500 lives could be saved per year. If we further assumed that each car with air bags had a life expectancy of 10 years, then during the lifetime of these 10 million cars perhaps 5,000 lives could be saved. Then the cost per averted death could be estimated at

$$\frac{(\$10 \times 10^9)}{5 \times 10^3 \text{ lives}} = \$2 \times 10^6/\text{life}^6$$

Some studies suggest that if air bags were used on all cars (about 100 million in the United States) then some number substantially less than 5,000 lives could be saved and, hence, the cost per death averted would be substantially greater than two million dollars.

Further, the use of air bags may, in fact, increase risks in a number of ways:

- They may provide a false confidence and cause people who would otherwise wear seat belts *not* to wear them. (The air bag is designed to work in only frontal-type crushes, and people not wearing seat belts in other types of crashes could be more severely injured, or even killed, if they neglected to wear seat belts.)
- Air bags have been known to fail, even in fatal crashes.
- When the air bags function properly, they may by their very nature induce specific injuries. Since air bags are designed to expand within one-fortieth of a second, the additional amount of energy that must be managed immediately following a frontal impact is increased. This increased energy, by its very nature, may cause injury. For example, the unrestrained child leaning against the windshield before a frontal collision could be thrown back instantaneously as the air bag explodes.

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\* These terms are stated in scientific notation. The term " $\$10 \times 10^9$ " translates to ten billion dollars; the term " $5 \times 10^3$  lives" translates to 5,000 lives; and the term " $\$2 \times 10^6/\text{life}$ " translates to two million dollars per averted fatality.

Table 3

REPAIR COST SAVINGS FROM  
1973 IMPROVED BUMPER DESIGN

Year*	Percent Savings
1973	4 to 17
1974	21 to 35
1975	8 to 26
1976	19 to 33
1977	1 to 32
1978	4 to 24

\*Compared with 1972 models.

end accidents could be reduced by using this rear light.<sup>5</sup> The number of fatalities reduced might be as many as 1,000 to 2,000 per year and the cost of implementing such a system could be as high as a billion dollars. So, we see that dollar cost per death averted is \$30,000 per year. Again, such a measure would be very cost effective.

We can look at a number of other entries on Tables 2A through 2E and demonstrate by example how the cost per averted fatality was estimated. The use of air bags on all cars (roughly 100 million cars), which would clearly be a design change, could save as many as 6,000 to 9,000 lives per year, and could reduce injuries by 300 percent. Because air bags might cost up to \$1,000 per car to install, the cost per fatality averted could be as high as one or two million dollars. If we assume that air bags cost \$1,000 per car to install and, in one year, they are installed in all cars manufactured in that year (roughly 10 million cars), then the cost to install air bags in all cars manufactured in one year would be

$$(\$1,000 \text{ per car})(10 \times 10^6 \text{ cars}) = \$10 \times 10^9,$$

or 10 billion dollars. Because 10 million cars represent about 10

<sup>5</sup> Reference 16 credits a 66.6 percent reduction in rear-end crash probability, and states that the cost of the average rear-end accident would be reduced from \$1,041 to \$396. References 11, 12 estimate that 1,200 fatalities per year would have been averted if all passenger cars were equipped with such a light. They further estimated that nearly 150,000 injuries could be averted, and that insurance companies could save perhaps \$1.31 billion in 1979 alone.

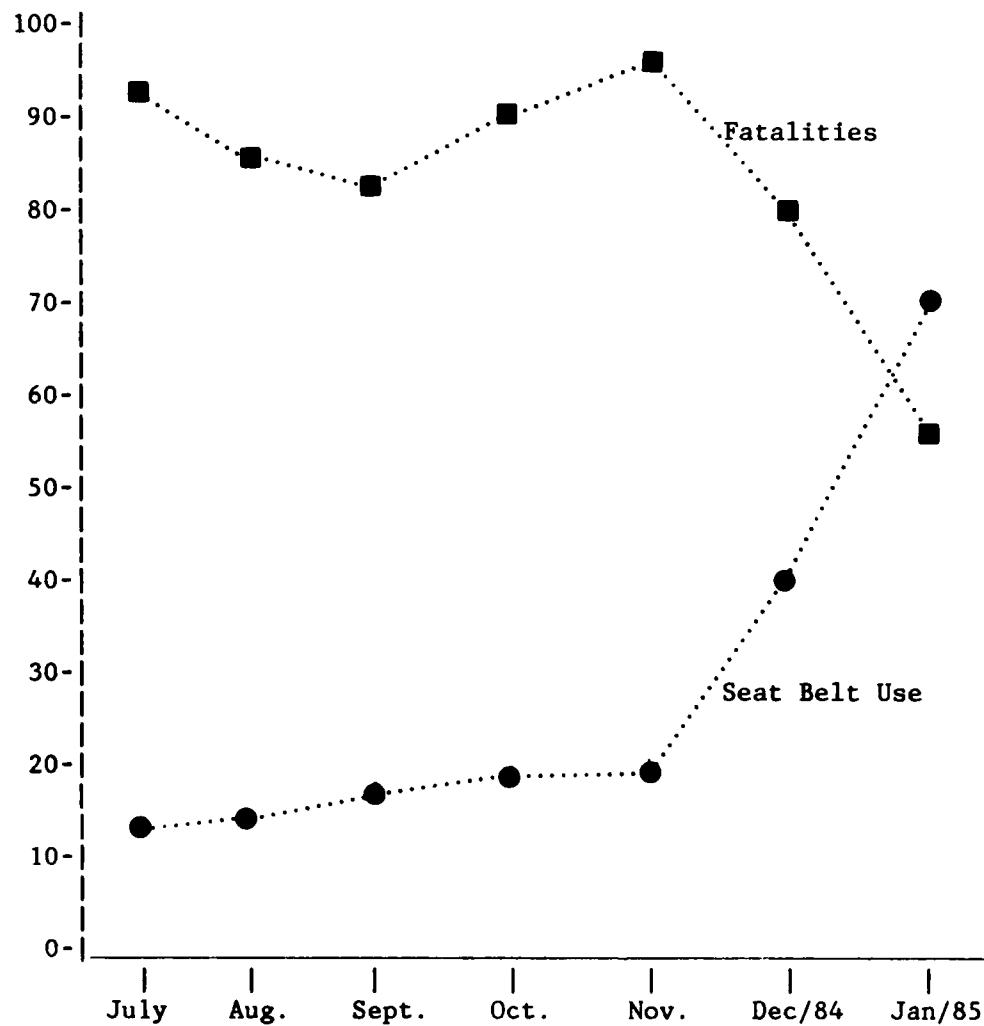
We can look at some examples where the industry has made design changes, thereby reducing fatalities and injuries. The installation of roll bars on utility vehicles (jeeps) has eliminated hundreds of fatalities per year at a cost of hundreds of millions of dollars. The cost per fatality averted is on the order of a million dollars [6]. Another industry design change, bumpers that prevent damage to cars if accidents are below 2.5 mph for rear bumpers, or 5 mph for front bumpers, generally does not reduce the number of fatalities. This makes sense because we would not expect any fatalities in an accident under 5 miles per hour. Also, the improved bumper design probably did not reduce the number of severe injuries by very much, but there was clearly a reduction in property damage.\* Based on estimates in [13] there is a dramatic dollar savings in repair costs associated with improved bumper design. These savings can be represented as a percentage savings relative to 1972 designs. Model 1973 cars were the first to have the 2.5/5.0 mph bumpers. The savings in repair costs are clearly a function of the relative sizes and weights of the bullet car and the impacted car. Table 3 illustrates the percentage savings across all sizes and weights from 1973 through 1978.

In another case, if the government required nationwide that children under 4 years of age use child restraint seats, then the number of deaths for children under 4 years old would be reduced by 500 per year, at a minimum. The cost of enforcing such a law would be billions of dollars and we might see about a \$100,000 cost per fatality averted. All would agree that this was very cost effective. Unfortunately, only a few states presently enforce the use of child car restraints.

A number of studies have considered the effect of having a rear brake light at approximately the height of the bottom of the car's rear window. Several concluded that as many as 50 or 60 percent of all rear-

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\* Before 1973, roughly 20 percent more accidents were reported. This 20 percent corresponds to those accidents resulting in damage in rear-end and front-end bumpers for impacts under 2.5 mph and 5 mph, respectively. The 1973 design improvement eliminated most of these claims.



Source: [22]

Fig. 2 -- Fatalities and use of seat belts

After observing statistics in Canada and Great Britain, countries which have enforced the mandatory seat belt law for several years, researchers note that the automobile operators most likely to be involved in a serious or potentially fatal accident are also those least prone to adhere to the seat belt law [22]. Hopefully, continued stringent enforcement of these laws will eventually conform the views of those motorists who still may tend to defy the law by showing the further decline in the number of highway fatalities.

The State of New York implemented a mandatory seat belt law in December 1984, and began enforcement on January 1, 1985 [22]. This move already has proved very effective, leaving many officials stunned at the dramatic decrease in fatalities. By the end of January this year, the State of New York documented its lowest motorist fatality statistics since 1926. And, the 15 percent of New York drivers who previously used their seat belts on a regular basis increased to a remarkable 70 percent.<sup>3</sup> A total decrease in fatalities of 27 percent was recorded in New York State after the first three months of 1985 [23]. Figure 2 relates the occurrence of fatalities and use of seat belts.

Officials believed that passage of the mandatory seat belt law would go largely ignored [22], but fines of \$10 to \$50 for failure to use a seat belt have proven an effective way to decrease fatalities. The increase in the percentage of seat belt users proves that adherence to the law, though considered a great annoyance by most drivers, is not an inconvenience too great to be overlooked in hopes of not being caught. The public is now showing support for the law. After seeing the actual statistics, appreciation for the benefits gained (reduction of serious injuries and fatalities, lower insurance rates, and a feeling of making a positive move to reduce their own risk) are clearly outweighing any inconvenience.

Even though the fines incurred from noncompliance are minimal, the measure remains cost-effective because enforcement agencies are not going out of their way to seek out every offender. Rather, almost all of the 4,500 offenders cited in January had been initially stopped for another violation [22]. The automotive industry has contributed about \$15 million to help pass these laws to avoid costly design reformations to include air bags; an implementation which they have long fought to avoid.

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<sup>3</sup> Estimates from the U.S. Department of Transportation state that national seat belt use averages 15 percent, and that 100 percent compliance would mean a 50 percent reduction in serious injuries and fatalities [22].

Table 2E  
APPROXIMATE DOLLARS PER AVERTED FATALITY  
(Continued)

Measure		Benefits			Cost Δ\$	\$/averted fatality (thousand \$)
		ΔF	ΔI	ΔN		
Tube vs. recap tubeless	D/G			260%*		50 (?)
Depth of tread	D/G			200%*		50 (?)
Lights on in day	D/G			Δ15% in front end		
Reflective plates	G			13% in rear end		
Mud flaps	D			1.3%		

An innovative and practical method to deter driving under the influence of alcohol has been taken in Midwest City, Oklahoma, by implementing a "scarlet letter" approach [21]. Specifically, when a driver has been convicted of driving while intoxicated he makes a choice between spending 30 days in jail or agreeing to flaunt an ostentatious bumper sticker stating that the driver has been convicted of drunk driving, and asking other vehicle operators to report any odd or erratic driving to the police. Drivers who choose to "wear the scarlet bumper sticker" may not park outside of any bar or liquor store and must display it for a full six months; any violators of these simple rules risk being sent to jail for 30 days.

On the other hand, let us examine a measure that improves driving habits *voluntarily*, such as seat belt use. If this measure proved 90 percent effective, as many as 28,000 lives might be saved. The financial campaign (the public service commercial associated with it) could cost only \$100,000 per fatality averted [6]. Another measure, a law *requiring* seat belt use, may save as many as 10,000 to 15,000 lives [6]. This assumes that the law was only about 50 percent effective in increasing seat belt use. We estimate that the cost of implementing such a measure might be \$200,000 per fatality averted.<sup>2</sup>

<sup>2</sup> Reference 14 suggests that if everyone used seat belts, we might see a reduction of about 10,000 fatalities per year. Reference 6 speculates that up to 15,000 fatalities might be averted.

Table 2C  
APPROXIMATE DOLLARS PER AVERTED FATALITY  
(Continued)

Measure		Benefits			Cost Δ\$	\$/averted fatality (thousand \$)
		ΔF	ΔI	ΔN		
Signs	G	1000's				68
Guard rail improvement	G	100's				68
Skid resistance	I	~500				84
Bridge rails	G	250-500				92
Wrong way entry	G	250+				100
Impact absorbers	G	1000's				216
Break away signs	G	500+				232
Median barrier improvement	G	1000's				456
Clear recovery	G					586
Remove trucks	G	1,250				very large

Table 2D  
APPROXIMATE DOLLARS PER AVERTED FATALITY  
(Continued)

Measure		Benefits			Cost Δ\$	\$/averted fatality (thousand \$)
		ΔF	ΔI	ΔN		
Remove large cars	G	10,000's				very large
Eliminate all auto fires	I	250				1000's +
Eliminate all auto fires, rear end only	I	100				1000's +
Standard 301	G	100's				200
Pink cars	G/D	1000's				5 (?)
Anti-skid brakes	I				10%	
Tube tire vs. non tube	D/G				360%	
Recap tube vs. non tube	D/G				480%	
						50 (?)

Table 2A  
APPROXIMATE DOLLARS PER AVERTED FATALITY

Measure		Benefits			Cost $\Delta \$$	$\$/\text{averted fatality}$ (thousand \$)
		$\Delta F$	$\Delta I$	$\Delta N$		
Stronger drunk laws	G	Up to 25,000	100,000+	200,000?	Billions	50
Stronger seat belt laws	G	Up to 15,000*	100,000+	0 or small	Billions	200
Voluntary seat belt	D	Up to 28,000**	200,000+	0 or small	Billions	100*
Roll bars — Jeep	I	100's	1000's	0 or small	100's millions	1000
Bumpers — 2.5/5.0 mph	I	0	~0	20% reduction	25% reduction	$\infty$
Child car seat	G	500***	1000's	Small	Billions	100
Rear light	I/G/D	1800	60% reduction	60% reduction	1.29 billion	30
1966-1970 auto equip.	I					260

\*50% effect.

\*\*90% effect.

\*\*\* 4 yrs.

\*Public service commercials

Table 2B  
APPROXIMATE DOLLARS PER AVERTED FATALITY  
(Continued)

Measure		Benefits			Cost $\Delta \$$	$\$/\text{averted fatality}$ (thousand \$)
		$\Delta F$	$\Delta I$	$\Delta N$		
Steering column +	I					200
Airbags	I	6,000-9,000	300% reduction			640
Tire inspection	I/D					800
65 mph to 55 mph limit	G/D	7,000-10,000	~100,000			<50
Rescue helicopters	G	10's				130
Passive 3 pt. harness	I					500
Passive torso belt	I					220
Driver ed.	G/D	100's				180
Highway maintenance	G					40

there is a cost associated with improving roads, adding road signs, and enforcing driving laws. This is a cost to the government that is passed on to the taxpayers. Commercials on television or on billboards that say "buckle up," "don't drive while intoxicated," and other such public service announcements may be paid for by large companies and organizations. In a sense, a public service announcement is something that the consumer or the taxpayer ends up paying for in the form of higher product costs or tax benefits enjoyed by the organization offering the commercial.

#### APPROXIMATE DOLLARS SPENT PER AVERTED FATALITY

In Tables 2A through 2E we list a number of measures that can be taken to reduce the risk associated with automobiles.<sup>1</sup> In some instances, we have identified the number of fatalities, injuries, and occurrences of property damage that are reduced. Also, we have compared the estimated benefit of implementing the measure, with the cost of putting the measure into place. We will discuss a few of the examples shown.

As stated previously, there are approximately 50,000 fatalities per year due to automobile accidents [2, 3]. One-half of these result because at least one of the drivers involved was driving while intoxicated [6]. Imagine if all drunk drivers were eliminated, by some fortunate method. We could prevent up to 25,000 fatalities and hundreds of thousands of injuries per year. Based on estimates by Solomon, Batten, and Phelps [6] the cost of such a measure might be approximately \$50,000 per fatality averted.

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<sup>1</sup> Symbol definitions for Tables 2A through 2E are as follows:

- G = Government has primary control over safety improvement measure.
- D = Driver has primary control over safety improvement measure.
- I = Industry has primary control over safety improvement measure.
- $\Delta F$  = Decrease in fatalities per year should safety measure be implemented on all cars.
- $\Delta I$  = Decrease in injuries per year should safety measure be implemented on all cars.
- $\Delta C$  = Decrease in accident dollar cost per year should safety measure be implemented on all cars.
- $\Delta S$  = Cost of implementing measures per year, industry-wide.
- \$/averted fatality = Cost per averted fatality measured in thousands of dollars.

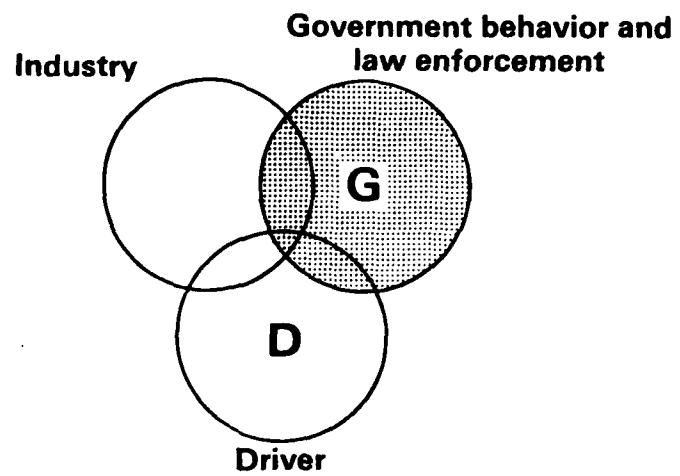
### III. ANALYSIS

#### COSTS OF RISK REDUCTION

Before discussing our analysis, we must define *reduced risks* for automotive design and the *costs* associated with reducing them. Reducing risks, improving safety, and increasing benefits are equivalent events. An increased benefit may be a decreased probability of incurring death or severe injury. Improved safety can be accomplished in a number of ways; and each method of improving safety has its own cost and benefit implications. It is up to the policymaker to determine which methods have the optimal mix of cost and benefit.

One measure of policy effectiveness is the number of fatalities averted per year. Before 1974, the speed limit on U.S. highways was 65 to 70 miles per hour and statistics showed an average of 55,000 deaths annually. When the speed limit was reduced to 55 miles per hour during the 1974 gasoline crisis, we saw a rapid decline in the number of fatalities per year to approximately 45,000. Currently, the number of fatalities has leveled to around 50,000 per year. Therefore, we see a reduced risk or increased benefit associated with a particular action. The benefit is the lower probability of death and the action is decreasing the speed limit. As we can see, there are additional benefits associated with this action--a lower probability of both severe injury and extensive property damage. Furthermore, because there are fewer accidents, there are fewer investigations by insurance companies, less compensation by insurance companies, and so on, resulting in even more dollars saved. Changing the speed limit will give rise to costs in the initial public announcement campaign, replacement of road signs, and law enforcement.

What are the costs of taking measures to reduce risks? The first thing that we want to consider is who is responsible for the cost. There is a cost to the industry for installing seat belts and other safety devices on cars, but that cost is very typically passed on to the consumer by adjusting the purchase price of the car. The consumer pays an incremental amount for each safety device that is added. Clearly,



**Fig. 1 -- Defining industry/law enforcement/driver role in improving safety: a typical issue**

combination of the government, or the industry, or the driver exercises some control. An example of a hybrid issue is seat belt use. The industry puts the seat belt in the car and the driver elects to wear it. Figure 1 succinctly summarizes the interrelationship between industry, law enforcement agencies, and the individual driver.

In some states, law mandates the use of seat belts. In the specific cases of child restraint seats and seat belt use there is a move toward mandatory use. In the State of California, and a number of other states, the parent (or any other person) driving with a child under 4 years old is obligated to keep that child restrained in a state approved car seat while riding in an automobile. In addition, a number of Air Force bases, including Kirkland Air Force Base in Albuquerque, New Mexico, require the driver and all passengers to wear seat belts while driving on base even though the speed limit seldom exceeds 30 miles an hour. Anyone caught without their seat belt will be fined.

- (2) For some prescribed level (accepted standard) of safety, we can spend whatever it takes to achieve that; or
- (3) We can weigh the marginal costs of reducing risk against the marginal benefits that result. The optimal decision is to add automotive safety measures until the benefit of the safety measure is equal to, or exceeds, its cost. However, this approach requires that the value of human life be explicitly stated.

We do not contend that any one of these three is better than the other two, but, for the purpose of our demonstration, we have elected to pick the first operational definition.

Assuming a fixed societal expenditure, how do we maximize automotive safety? We propose that a specific way of implementing such a measure would be to enforce the most cost-effective measures first. We would see the highest payoff--in terms of improved safety--at the lowest dollar cost [6]. A good example of this is a mandatory seat belt law which will be discussed later in more detail.

#### **DEFINING ROLES IN IMPROVING SAFETY**

As discussed earlier, three groups can control the safety of automobiles--the industry, the government, and the driver. The industry could add seat belts or air bags or make other design changes to improve safety. At the state level, the government could improve highway conditions and add road signs; the police and law enforcement agencies could provide stricter enforcement of drunk-driving and speed limit laws; and, the judicial system could more stringently penalize offenders. Last, the driver could improve driving habits in many ways such as by reducing speed and using a seat belt at all times. Associated with each of these actions is a cost. For these examples, cost is in the form of dollars expended or time lost. Whoever pays these costs is determined by the measure taken.

We find that some issues are rather distinct in terms of who can control safety; the voluntary maintenance of one's automobile is clearly the driver's prerogative. Other issues are hybrid; that is, a

## WHY ALARA?

Let us examine ALARA more carefully and try to understand why it is a sensible goal for the automotive safety application. Realistically speaking, our society is constrained in expenditures and budgetary resources. Therefore, we cannot spend an infinite amount of money to avoid a fatality. Currently, approximately 50,000 fatalities and hundreds of thousands of injuries result each year from automobile accidents. If everyone drove a Sherman tank at a speed of 3 mph or less, these statistics would be reduced substantially (but not likely eliminated). On the other hand, the costs associated with this scenario are insurmountable. This example illustrates how impractical it is to eliminate risk without regard to budgetary constraints. Therefore, as long as we drive there will be a finite probability of a fatality. As another example of minimizing risk without a budget constraint imagine eliminating air-travel risk. This would mean that all cross-country travel by aircraft would stop. If someone needed to travel from Los Angeles to Washington, D.C., the traveler would be forced to take a slower, safer means of transportation such as a train. But for some people, safer means of transportation do not compensate for resource costs (such as time lost). Consequently, this does not efficiently allocate resources.

From these examples the ALARA risk reduction goal is clearly the most sensible. When speaking of automotive safety we want to minimize risk of injury, death, or property damage but budget constraints do exist. By using the ALARA Goal we achieve our goal while considering resource costs.

Before applying the ALARA principle to automotive safety and design, we must emphasize the fact that *there is no unique definition of ALARA as it is applied to improving automotive safety*. We can conceive of at least three rather distinct, operational definitions.

- (1) For a fixed societal expenditure, we can maximize automotive safety--reduce the risk of driving to as low as possible;

- The propellants used in air bags may be carcinogenic. If air bags are installed in all cars on the road, we might expect to have to dispose of roughly twenty million canisters (2 per car for 10 million cars) of carcinogenic propellant per year.

If we perform an extremely conservative calculation of the worth of air bags, we might disregard the negative features of air bags discussed; we might assume that air bags installed on 100 million cars would save 10,000 lives per year, and that air bags would cost only \$640 per car to install. Using these very conservative assumptions, we would estimate a cost per averted death of \$640,000--still a high number.<sup>7</sup> The use of air bags would be considered far less cost effective than the use of child restraint seats.

These tables list a number of other measures that could be taken by government, industry, or drivers, stated in dollars per averted fatality. Cost per averted fatality ranges from as low as \$30,000 to as high as several million dollars.

#### **WHAT THE AUTOMOBILE INDUSTRY HAS DONE TO IMPROVE SAFETY**

Figure 3 divides measures that have actually been implemented from those that have not. It also illustrates cost per death averted and whether the measures are predominately controlled by industry, government, or drivers. For measures actually implemented, we find that approximately \$150,000 to \$600,000 per fatality averted has been spent by the auto industry. These measures include: adding skid resistant properties to the braking system, improving steering columns, adding additional rear reflectors, and offering a three point harness seat belt.

To look at what several state governments have spent to reduce the number of fatalities per year we consider the law requiring child restraint seat use. The cost of implementing child car seat laws to these states is approximately \$100,000 per fatality averted. Other

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<sup>7</sup> It is interesting to note that if air bags were used in conjunction with much stricter anti-drunk-driving laws, the cost per averted fatality for air bag use would increase, since many of the accident-causing drunk drivers would be no longer on the road.

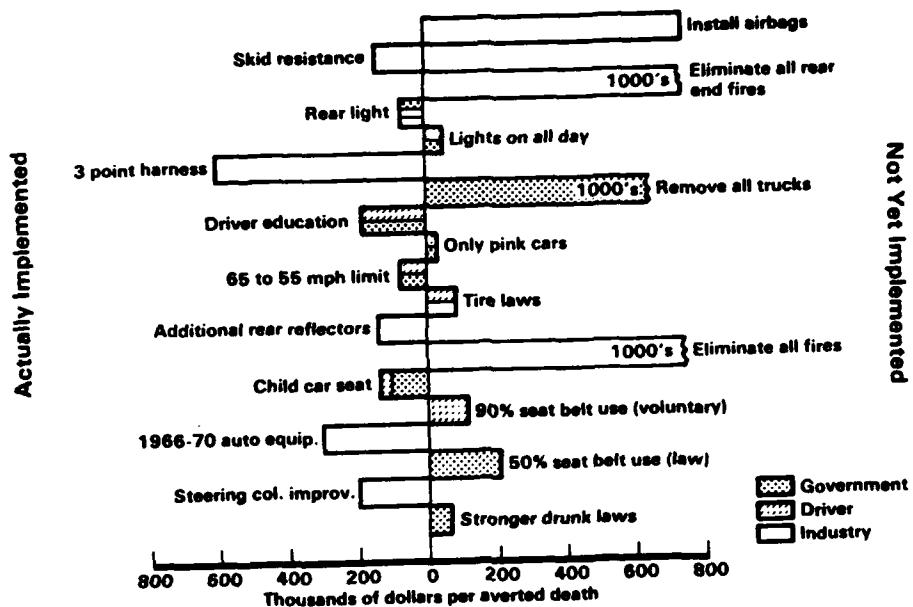


Fig. 3 -- Measures implemented by the automotive industry to improve safety

possible measures subject to government control are reducing the speed limit from 65 to 55 mph and mandating the use of the high, center-mounted rear brake light. Each measure would cost on the order of \$30,000 to 50,000 per death averted.

If we compare measures that were actually implemented with those that have not been implemented, we see a rather interesting contrast. Of those not yet implemented, we can divide the measures into two general categories: those that are very expensive to implement (millions of dollars per fatality averted), and those that are relatively inexpensive to implement (typically, \$50,000 to \$200,000 per fatality averted). Of those that are very costly, three of the four fall on the industry's shoulders; these are (1) to eliminate specifically, rear-end fires in automotive accidents, (2) to eliminate

all fires in automotive accidents, and (3) to install air bags. The fourth, to remove all trucks from highways, falls on the regulatory branch of the government.\*

On the other hand, for relatively modest costs a number of fatalities could be prevented. Such fatality-averting measures might include, stronger drunk-driving laws<sup>3</sup> or a requirement that headlights be on all day. The former requires government action, and to a lesser extent, driver action. The latter is more a function of driving habit, but in fact could also be a function of law enforcement agencies. Both would save a fatality for approximately every \$50,000 expended.

Take what seems to be a ridiculous situation, requiring that all cars be pink. We find that the cost of implementing such a measure would be fairly modest relative to the number of lives saved. This is partly due to the belief that pink cars are least likely to be involved in accidents. In all fairness, this is a correlation as opposed to a causation. That is to say, it is not because they are pink that they are involved in fewer accidents; it is that perhaps people who drive pink cars tend to be more cautious. In any event, if we took the information rather literally and did not assess it carefully, we might facetiously say that if everyone drives pink cars, the cost of reducing the number of annual fatalities is rather modest.

A number of other measures could be taken by the government and drivers which, if implemented, would cost a rather modest amount of money to prevent deaths.

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\* While trucks account for 6 to 8 percent of total freeway mile use, they contribute to as many as 50 percent of the fatalities due to rear-end collisions [16]. A typical accident involves a car rear-ending a slow-moving truck on a freeway.

<sup>3</sup> Implementation of such a measure as stronger drunk-driving laws may have significant social costs associated with it such as increased police patrols, busier courts, larger jails, and so on. The issue of how to implement stronger drunk-driving laws will be the subject of a forthcoming paper.

#### IV. IMPLICATIONS

##### THE \$10,000,000 MENU

How many lives can be saved for a \$10,000,000 expenditure? Another way of comparing risk reduction measures is to consider that we have only a limited amount of money to spend. Suppose you had ten million dollars. There are several ways in which to spend this money, and each way determines a different number of fatalities that could be averted.

Figure 4 summarizes seven ways to save lives given a fixed resource of ten million dollars. In Case One, you would mandate that all automobile fires be eliminated, and you can spend ten million dollars in a lump sum to eliminate these deaths. Each ten million dollar expenditure will prevent approximately one death. We have already seen a 300 percent reduction in fire deaths when Federal Vehicle Safety Standard (FMVSS) 301 was implemented. This standard, FMVSS 301, dictates certain test requirements that cars and trucks must satisfy. These standards reduce the probability of fire. An example is that passenger cars must be able to withstand a 30 mph frontal barrier impact with fluid loss of less than 1 ounce per minute. Case Two, a situation that has been implemented, reduces the speed limit from 70 or 65 miles an hour to 55 miles an hour. Each ten million dollars expended will buy you approximately 200 averted deaths. In Case Three, stricter enforcement of seat belt laws, each ten million dollars will buy you approximately 50 averted deaths. To some extent, that has been implemented in New York State and on several Air Forces bases. In Case Four, stronger drunk-driving laws, each ten million dollar expenditure will buy you perhaps 200 averted deaths. We have seen stronger and stronger drunk-driving laws being implemented over the past few years. Case Five, child car seat enforcement, suggests perhaps 100 averted deaths for each ten million dollar expenditure. Child car seat laws are required as of mid-1984 in 7 states. Air bags, Case Six, will buy about

12 averted fatalities, and pink cars, Case Seven, might buy 2,000 for each ten million dollars expended.<sup>1</sup>

- Case 1:**      **Eliminate all death by fire**  
                  ~about 1 averted death
- Case 2:**      **Reduce speed limit from 65 to 55 mph**  
                  ~about 200 averted deaths
- Case 3a:**     **Seat belt enforcement law**  
                  ~about 50 averted deaths
- Case 3b:**     **Voluntary seat belt use**  
                  ~about 100 averted deaths
- Case 4:**      **Stronger anti-drunk laws**  
                  ~about 200 averted deaths
- Case 5:**      **Child car seat**  
                  ~about 100 averted deaths
- Case 6**        **Install airbags**  
                  ~ about 12 averted deaths
- Case 7:**      **Buying only pink cars**  
                  ~about 2,000 averted deaths

**Fig. 4 -- The \$10,000,000 menu:  
Save as many lives as you can**

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<sup>1</sup> As discussed earlier, the use of pink cars is only correlated with reduced accidents, and does not likely reduce accidents themselves. People who drive pink cars may be more careful drivers. Also, if all cars were pink, we may not expect much of a decrease in accidents.

### THE BOTTOM LINE

Industry has, in fact, implemented a number of cost-effective measures to date. Changing driving habits and stricter law enforcement will lead to more cost-effective means of saving lives.

While the means of implementing measures to improve safety is beyond the scope of this presentation, it suffices to say that more effective and stricter law enforcement against drunk drivers and people who fail to use seat belts and child restraint seats will provide the greatest benefit per dollar spent.

The decision by the State of New York to enforce the mandatory seat belt law is a direct and effective step in improving safety on our highways. Enforcement in New Jersey, Illinois, Michigan, and Missouri for seat belt use will begin this summer, and 32 other states are considering instating such a law. Should the implementation and enforcement spread nationwide, a great number of fatalities will be averted in the future. Hopefully, law enforcement agencies will be influenced enough by the statistics of deaths averted to enforce this law stringently. And, agencies hopefully will go after the drunk driver with a rigid campaign to help rid our highways of another great hazard--a hazard over which the drinker has sole control--to provide more complete safety for law-abiding motorists.

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